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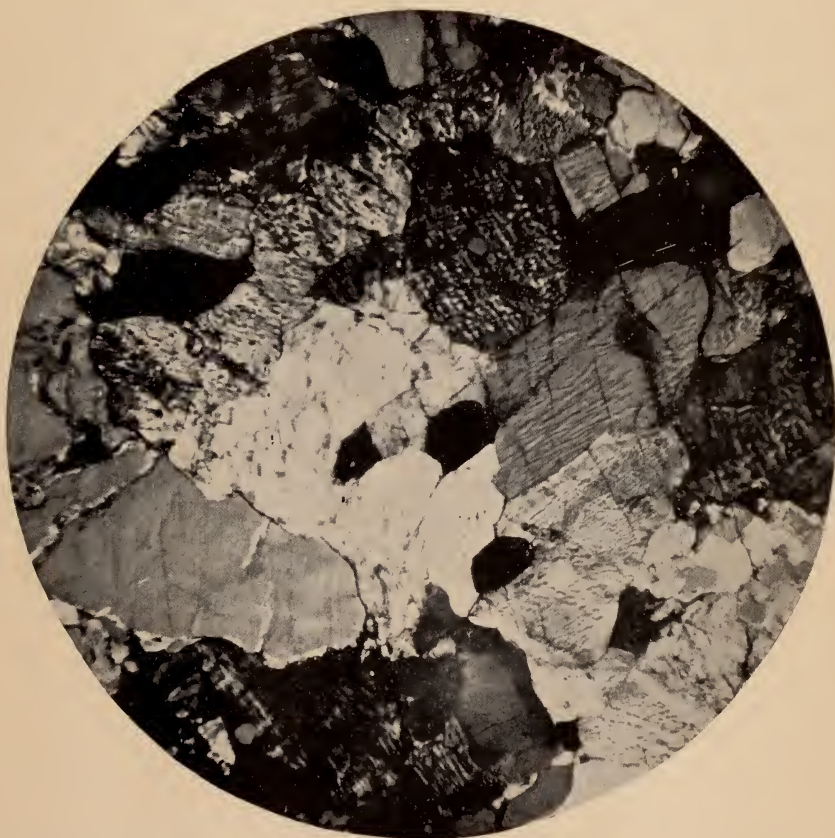
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PLATE I.



F. J. H. Merrill, Photo.

PRECAMBRIAN GRANITE, BREAKNECK MT., N. Y.

Photomicrograph in polarized light, enlargement 22 diameters.



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PLATE II.



F. J. H. Merrill, Photo.

PRECAMBRIAN GRANITE, KING'S QUARRY NEAR GARRISONS, N. Y.

Photomicrograph in polarized light, enlargement 22 diameters.



PLATE III.



F. J. H. Merrill, Photo.

PRECAMBRIAN SHEARED GRANITE, LAKE MAHOPAC, N. Y.

Photomicrograph in polarized light, enlargement 22 diameters.



[Reprinted from *New York state museum report*, 1896]

## APPENDIX A

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### THE GEOLOGY OF THE CRYSTALLINE ROCKS OF SOUTHEASTERN NEW YORK.

BY FREDERICK J. H. MERRILL.

This paper contains a synopsis of the results of an investigation begun in 1883 and carried on at personal expense till 1890, from which time till 1893, small sums were afforded from the funds of the New York State Museum for continuing the field work. In 1895, there being no museum funds available for this purpose, the Director of the United States Geological Survey contributed \$200 for completing the Precambrian and Palaeozoic geology of the Harlem sheet of the United States topographic atlas, embracing the region about New York city. A copy of this Geologic map and of the descriptive text were furnished to Director Walcott and will be incorporated in the New York Folio which is soon to be published.

The preliminary results of the general investigation were published in the *American Journal of Science*, series 3, vol. XXXIX, p. 389. The geologic mapping of the whole area east of the Hudson in New York was published in the *Economic and Geologic map of New York*, by F. J. H. Merrill, and in the *Preliminary Geological Map of New York\**, compiled and published by W. J. McGee, under the direction of James Hall, State Geologist.

The geology of Westchester county is also shown on a scale of four miles to the inch, in the *Geologic Map of a Part of Southeastern New York*, by F. J. H. Merrill, published in Bulletin No. 15, of the New York State Museum, which also forms part of the 48th annual report of the New York State Museum. This bulletin also contains the *Economic and Geologic Map*.

In completing the work for the Harlem sheet of the New York folio the writer had an opportunity to review the ground in com-

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\* The draft of the southeastern crystalline area for this publication was prepared at the request of Prof. Hall in 1893 and was not revised before engraving, so that it differs slightly from the map of Southeastern New York which contains the results of additional field work.

pany with Prof. C. R. Van Hise and secure his criticism and approval of the principal points discussed.

With the permission of the Director of the United States Geological Survey, the data obtained under his auspices in the field work of completing the Harlem sheet are herewith incorporated.

## THE CRYSTALLINE ROCKS OF SOUTHEASTERN NEW YORK.

The crystalline rocks of southeastern New York lie on the east of the Hudson River, in New York, Westchester, Putnam and Dutchess counties, from whence they extend into Connecticut; and on the west of the river, in Orange and Rockland counties, whence they extend southwesterly into New Jersey. The lowest member is a coarse hornblende granite which forms the central mass of the range of mountains known as the Highlands of the Hudson, and, in their highest peak, Breakneck Mountain, is exposed through a vertical height of nearly 1,200 feet. (Pl. I.) With these greater masses of hornblende granite, are associated other local masses of granite comparatively free from hornblende, which are extensively used for building stone. (Pl. II.) These granites are probably igneous and of great age, and on their flanks are banded gneisses consisting chiefly of quartz and orthoclase with biotite and hornblende, containing numerous beds of magnetic iron-ore. The gneisses on the south side of the Highlands (Pl. III) extend through Westchester county in a series of folds with southwesterly trend, and on the northern slope of the Highlands at several places in Dutchess county, are overlain unconformably by Palaeozoic basal quartzites, which are believed to be of Cambrian age and are bordered by Ordovician limestone and slate or schist. Some of the principal valleys of Putnam county contain belts of limestone associated with quartzite and mica schist, which are probably to be correlated with similar rocks hereafter described as altered palaeozoic strata.

From the relation of the quartzite, limestone and schist of Westchester county to the underlying gneiss, which is precisely similar to that of the Palaeozoic strata in southern Dutchess county and

Putnam county to the subjacent gneiss, and from the nearly complete stratigraphic continuity, it is inferred that the crystalline limestone of Westchester county is equivalent to that of southeastern Dutchess county, the age of which has been satisfactorily established by the work of Dwight, Dana, and others to be Calcareous-Trenton, and the schist and micaceous gneiss overlying the limestone by like analogy is considered to be of Hudson river age.

Besides the older granites just mentioned, there are in Westchester and New York counties many later eruptive rocks of considerable areal importance.

Prominent among them is a red granite consisting chiefly of quartz, orthoclase and biotite which is injected into and through the gneiss at many points, and at Sing Sing, through the overlying limestone. In Yonkers township is a large area of reddish granite quite gneissoid in texture, which is intrusive in the Fordham gneiss.

The mica schist has been specially subject to igneous intrusions. Within its areas occur the Cortland series of diorites and norites described by J. D. Dana\* and Geo. H. Williams,† the Harrison diorite described in detail by H. Ries,‡ the serpentines which are altered eruptives and certain gray granites which occur in domes, bosses and lenses in the southernmost part of Westchester county. Near the shores of Long Island Sound the Manhattan schist is everywhere injected with bands, lenses and dykes of pegmatite, granite, amphibolite and pyroxenite.

All the stratified crystalline rocks above described, with the possible exception of the Fordham gneiss, were originally sediments laid down in horizontal strata, the quartzite representing a beach deposit, the limestone, a deposit in water unaffected by wash from the land and probably of warmer temperature, and the schist a deposit of sandy mud in shoaler water. These three rocks form a reliable record of a period of subsidence of the land and transgression of the sea with subsequent recession and emergence.

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\*Am. Jour. Sci. III, Vol. xxii 1881 pp. 103-119.

† " " " xxxi 1886 pp. 26-41.

xxxiii 1887 pp. 135-144; 191-199.

‡ Trans. N. Y. Acad. Sci., Vol. xiv., 1895 pp. 80-86.

At a time or at times not accurately determined, but which probably began not later than the Upper Silurian, and may have continued at intervals to the end of the Palaeozoic, these horizontal strata by lateral pressure were thrown into parallel folds throughout a broad belt of country having a general northeasterly trend and with the Palaeozoic beds, the underlying rocks of greater age were also folded. As the cross sections show, the folds are closely compressed and in many cases are overthrown to the eastward and westward, so that frequently the rocks on both sides of the fold dip in the same direction. Associated with the longitudinal folding of these rocks was a transverse folding, the general result of which was elevation at the northward, so that the parallel ridges with their intervening valleys as a rule, pitch or slope very gently to the southwest. There are local variations from this general condition and some of the folds have locally a northward pitch, but the general condition may be noticed in the western ridges of Fordham gneiss which in the town of Yonkers attain a height of 300 feet, and on Manhattan Island pass below the sea level and do not reappear.

As already stated these rocks may be classified in the following manner:

### CRYSTALLINE ROCKS.

#### Ordovician:

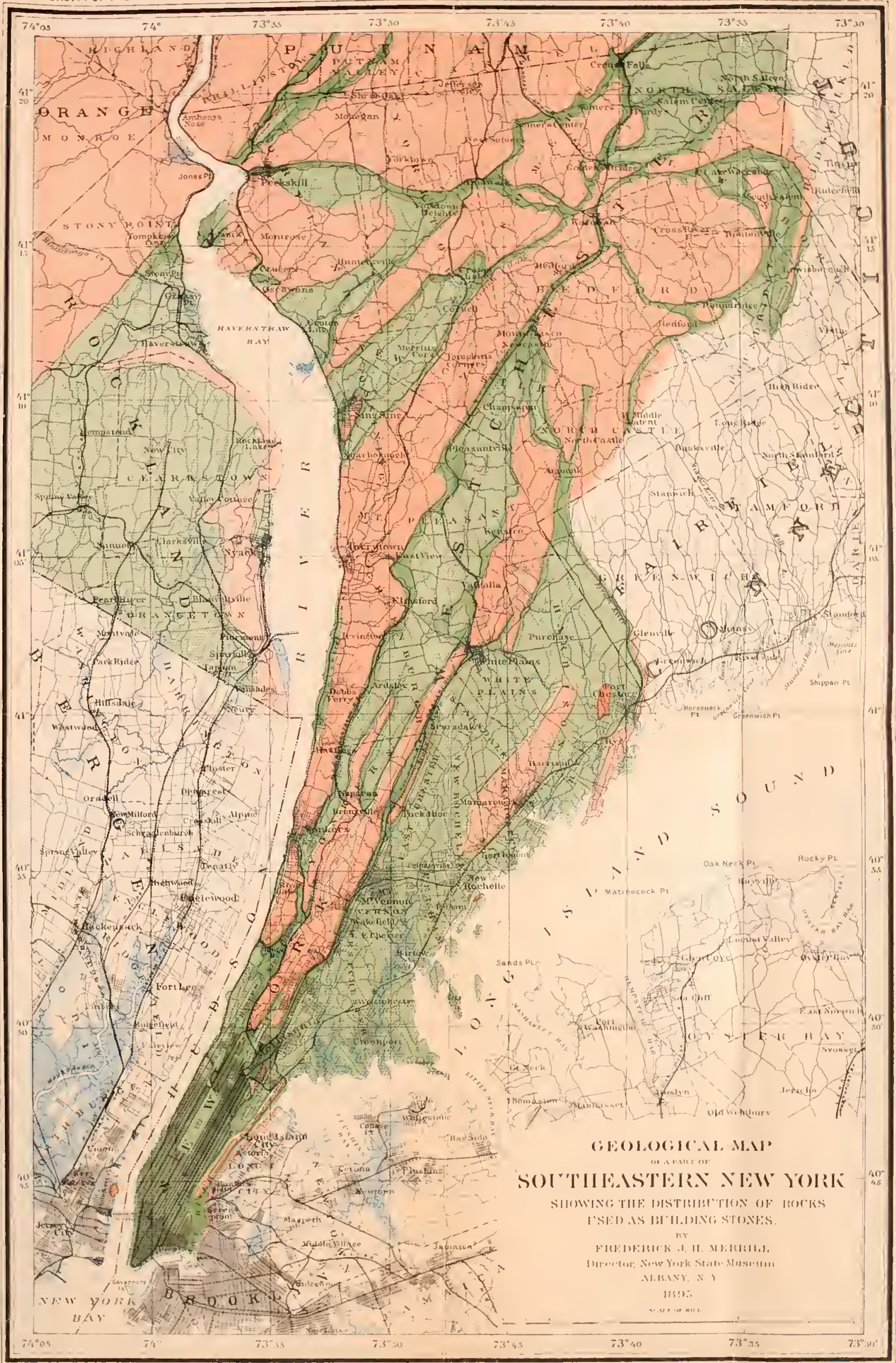
- 1 Manhattan schist, containing garnet fibrolite, kyanite and staurolite.
- 2 Inwood limestone, crystalline dolomite, containing diopside and tremolite.

#### Cambrian:

Lowerre quartzite

|                   |   |                                 |
|-------------------|---|---------------------------------|
| Precam-<br>brian. | { | Algonkian? Fordham gneiss       |
|                   |   | Archaeon { Gneisses<br>Granites |

For detailed examination of these formations, it has been necessary to depend largely on the exposures along the east shore of the Hudson river and those in southern Westchester county and on New York Island. In central, eastern and northern Westchester county, the quaternary deposits of stratified and unstratified drift



| LEGEND                                                                              |         |            |                    |                 |                   |                                   |            |         |                  |         |  |
|-------------------------------------------------------------------------------------|---------|------------|--------------------|-----------------|-------------------|-----------------------------------|------------|---------|------------------|---------|--|
| GEOLOGICAL AGE AND CHARACTER                                                        |         |            |                    |                 |                   |                                   |            |         |                  |         |  |
| IGNEOUS                                                                             |         |            |                    |                 |                   | TRIASSIC                          |            |         | LOWER SILURIAN   |         |  |
| THUASIC DIABASE, ALTERED BASIC ROCKS, COBALT SERIES, HARRISON DIORITE, YONKONGTILES |         |            |                    |                 |                   | HUDSON, TIVELY, CALDWELL, STENTON |            |         | PRE-CAMBRIAN     |         |  |
| SCIENTIFIC NAME                                                                     | DIABASE | SERPENTINE | DIORITE AND NORITE | GRANITE DIORITE | ANDESITIC DIABASE | SANDSTONE                         | MICA SLIST | HOLOMIT | GREENISH GRANITE | GRANITE |  |
| COMMERCIAL NAME                                                                     | TRAP    | GRANITE    | GRANITE            | GRANITE         | SANDSTONE         |                                   | MABLE      |         |                  |         |  |



are so thick and extensive that the outcrops are few. The localities discussed are therefore chiefly confined to the vicinity of New York city.

The stratified crystalline rocks within the area under consideration, which is south of the 41st parallel, belong to two principal divisions, the Precambrian and the Palaeozoic. Of the Precambrian only one member can be recognized, which has been called the *Fordham gneiss*. Of the Palaeozoic there are two persistent members, the *Inwood limestone* and *Manhattan schist*, and a third of local and slight development, the *Lowerre quartzite*, which underlies the limestone.

## PRECAMBRIAN.

### FORDHAM GNEISS.

The Fordham gneiss, named from the former town of that name, within which it is well exposed, is a gray banded gneiss varying much in the composition of its bands or layers, which, as a rule, are quite thin, rarely exceeding two inches in thickness. Some of these are highly quartzose (Pl. IV.), some are largely composed of biotite and some consist of pegmatite or granite which has been injected parallel to the regular banding of the gneiss. Hornblende is an occasional constituent of this rock but, though highly persistent in some bands, does not occur over large areas of country. Garnet is present rarely in but small quantity.

As the schistosity of the Fordham gneiss has usually a very steep dip the exposures of this rock chiefly show cross sections of the banding.

It is difficult to give this rock formation a systematic name which exactly indicates its age. If it is of sedimentary origin it may be called Algonkian, but it can only certainly be said that it is Precambrian.

The Fordham gneiss forms the high anticlinal ridge which borders the New York shore of the Hudson River from Yonkers southward to Spuyten Duyvil and also that on the west side of the Bronx valley. The former ridge terminates on the south at Spuyten Duyvil and does not reappear on Manhattan Island. The latter is bifurcated at

the southern end and the western fork interrupted by a cross fold at the Harlem River, ends on Manhattan Island in the low ridge which borders Seventh avenue on the west at One Hundred and Fifty-fifth street, and disappears by pitching below the general surface level about half a mile southward. The eastern fork which, owing to the same cross fold, disappears beneath the limestone in Morrisania, reappears near the Bronx Kills in Mott Haven, where it forms a low anticlinal ridge interrupted by the Kills and represented on Manhattan Island by a few outcrops below high water mark at the foot of East 123rd and 125th streets which are now obliterated. Some narrow anticlinal ridges of Fordham gneiss are seen on the islands in the East River, notably Blackwell's, Ward's, N. Brother's and S. Brother's, and it is the only stratified crystalline rock at present exposed on Long Island, where it may be seen near the court house in Long Island City and at intervals on or near the shore of the East River from Ravenswood to Lawrence's Point. It is also found in deep well borings and is the subterranean of western Long Island.

### PALAEOZOIC.

At the base of the metamorphosed Palaeozoic limestone and overlying the Fordham gneiss is a stratum of thinly bedded quartzite. This deposit occurs in southern Westchester county near Lowerre station in Yonkers, at the Hastings marble quarry and about one-quarter mile south of Sparta on the shore of the Hudson River. It is well shown north of Peekskill along the east shore of Annsville Cove and in the valley of Peekskill Hollow Creek near Oregon. It does not exceed sixteen feet in thickness at Hastings. From the name of the southern locality this is called the Lowerre quartzite. Its age is probably Cambrian and possibly Georgian.

### INWOOD LIMESTONE.

This is one of the most prominent formations of the region mapped and is a coarsely crystalline dolomite, distinctly bedded and containing at many localities the lime-magnesia silicates, diopside and tremolite, and occasionally tourmaline. Of its maximum thickness little is definitely known. At Tuckahoe a thickness of one hundred and

PLATE IV.



F. J. H. Merrill, Photo.

FORDHAM GNEISS, LEFURGY'S QUARRY HASTINGS N. Y.  
Photomicrograph in polarized light, enlargement 22 diameters.



fifty feet is shown in section. In the Harlem River a thickness of about seven hundred feet is indicated.

The age of this limestone is probably Calciferous-Trenton. In the absence of fossils, which could not have withstood the extreme metamorphism, the exact age is indeterminate.

The crystalline limestone, though frequently well exposed, must often be traced by its absence as well as its presence. Its solubility in water containing carbonic acid renders it an easy prey to the elements, and its position is almost everywhere emphasized by low ground and usually by deep valleys. Throughout all the principal valleys small outcrops may be found, though usually for considerable distances it is buried in river gravel and alluvium. Where it has undergone the maximum of leaching the granular particles of limestone have disappeared entirely and in its stead we find a mass of aluminous and magnesian material, whitish, green with scales of prochlorite, red with peroxide of iron, and sometimes black with separated carbon. In these conditions it is often mistaken for clay or kaolin, and was thus reported from the railroad cutting at Morrisania, from the Blackwell's Island tunnel and from dredgings in the East River on the Middle Ground, Shell Reef and at the mouth of Newtown Creek. The same material was also found overlying the Fordham Gneiss in a deep boring on Tallman's Island near College Point. On the uplands the presence of limestone is evidenced by coarse yellowish white sand, consisting of partially dissolved cleavage fragments of the dolomite. This may be seen on the plain east of Inwood.

To the presence of the limestone is due the commercial prominence of New York, as all the navigable channels about the city are submerged valleys which owe their origin to the solution of the limestone along the lines of its outcrop and exposure. Without the submergence the limestone valleys would not be navigable channels and without the presence of limestone there would have been no valleys for the submergence to render navigable.

Long Island Sound near New York owes its existence to the same cause, as it is the locus of a broad exposure of limestone uncovered by the removal of the Manhattan schist east of the Westchester shore.

## MANHATTAN SCHIST.

This formation covers a larger area than any other within the limits of the Harlem sheet, and is the uppermost of the crystalline groups. The rock is essentially a mixture of biotite and quartz, frequently containing enough orthoclase to give it the composition of a gneiss. The principal accessory is garnet, which occurs in crystals varying from one-sixteenth to one-quarter of an inch in diameter. Occasionally much larger crystals are found. Fibrolite, kyanite and staurolite are also frequent accessories. The Manhattan schist has a marked schistosity which is frequently nearly parallel to the bedding, though not always.

The aspect of this formation is intimately affected by numerous igneous intrusions and injections of granitic and basic material, which, in some places, are so numerous as to predominate over the schist. The small masses are for the most part parallel to the schistosity, though in part, oblique to it. The larger areas usually have their longer diameters parallel to the strike of the schistosity. They are most abundant near the shores of Long Island Sound.

As the geologic map shows, in southern Westchester county, the Manhattan schist is the prevailing rock east of the limestone valley in which lies the New York and Harlem Railroad. This eastern area is closely folded and its bedding planes are mostly on edge. It terminates at its southern extremity in a closely pressed synclinal fold, pitching northward, which crosses Randall's Island and Ward's Island and ends at Little Mill Rock in Hell Gate. Flood Rock, which was removed in the improvement of Hell Gate channel, was part of this synclinal. On Mill Rock the schist is much injected with amphibolite and pegmatite.

The Manhattan schist is also the prevailing rock on New York Island.

## IGNEOUS ROCKS.

Under this head are classified those rocks which are clearly intrusive in the Fordham gneiss, the Inwood limestone and the Manhattan schist.

So far as we know, they belong to one general period of igneous activity, the time of which can not be stated with greater exactness

than that it was posterior to the deposition of the Manhattan schists and therefore post-Hudson River, and prior to at least a part of the dynamic disturbance and crumpling of these rocks with which the intrusives have become schistose and even crumpled. The igneous rocks which occur in the Precambrian and Palaeozoic within the region south of the 41st parallel of latitude may be classified as follows:

- Yonkers gneiss
- Granites, red and grey
- Pegmatite dykes, very coarse
- Harrison diorite
- Amphibolites and pyroxenites
- Serpentines, derived from basic intrusives.

#### YONKERS GNEISS.

In an article on the Metamorphic Strata of Southeastern New York\*, the writer called attention to a reddish gneiss which appeared to be the lowest stratum in that terrane. From the microscopic structure of this rock, studied at certain localities, and from its apparent relations to the overlying gray gneiss, the conclusion was formed at that time that it was a metamorphosed sedimentary rock. More extended observations on this formation made during the summer of 1891 showed that it was not uniformly persistent as a basal member in southern Westchester county, and that it was not limited to the axes of the eroded anticlinals. The fact that it was overlain by a varying thickness of the gray gneiss was noticed by the writer at an early date but was attributed to unequal repetition of the gray gneiss by folding. Later investigations showed that a rock of the same composition occurred frequently as an intrusive either in veins and dikes or in bosses like the one at Sparta.

The Yonkers gneiss is technically a gneissoid granite. (Pl. V.) It is a well foliated rock consisting of quartz, reddish orthoclase and biotite with a little plagioclase. It is plainly intrusive in the Fordham gneiss and has become completely schistose.

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\*Am. Jour. Sci. III, Vol. XXXIX, p. 389.

In the particular area where this rock has its greatest extent it has been subjected to greater dynamic action than elsewhere and has been reduced to a gneissoid condition.

The persistence of reddish orthoclase in this rock suggests that it has sprung from a common source with the numerous dykes of red pegmatite and granite of similar composition which penetrate the schist and limestone at many points in Westchester county.

### GRANITES.

Gray and reddish granites in small dykes oblique to the banding of the gneiss and schists are quite abundant, but of more frequent occurrence are lenses and injections of granite and pegmatite parallel to the banding of the schistosity. Bosses of pegmatite frequently occur in the Manhattan schist. A granite area of considerable size occurs near Union Corners and many have been found on New York Island, which are now built over and concealed from view. The small islands and reefs in the upper Bay and most of those in Long Island Sound owe their existence to intrusions of granite and other eruptives in the schist, which by their hardness have resisted erosion.

### PEGMATITE DYKES AND BOSSES.

These are intrusions of coarse granitic material in dykes and bosses from one to ten feet in diameter. They are most abundant in the Manhattan schist.

### HARRISON DIORITE.\*

This rock is intrusive in the Manhattan schist in the town of Harrison and consists of orthoclase, plagioclase, quartz and hornblende. A smaller area of similar rock occurs at Ravenswood, L. I., where it outcrops in a long narrow ridge of northeasterly trend and is intrusive in the Fordham gneiss.

The mass which forms Milton Point near Rye has been subjected to much dynamic action and is well banded. The same rock is abundant along the shore of Long Island Sound between Portchester and Greenwich and is abundant in Greenwich and Stamford townships.

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\* H. Ries Trans. N. Y. Acad. Sci. 1895 Vol. xiv pp 80-86.

PLATE V.



F. J. H. Merrill, Photo.

SHEARED GRANITE (YONKERS' GNEISS), HASTINGS, N. Y.  
Photomicrograph in polarized light, enlargement 22 diameters.



## AMPHIBOLITES AND PYROXENITES.

Intercalated with the Manhattan schist and also with the beds of the Fordham gneiss, we find at a great number of localities on New York Island and in Westchester county, hornblendic and augitic bands and lenses of limited thickness, usually only a few feet. In composition, these rocks resemble diorites and diabases, and in structure they are granular, and though they are at present in a foliated condition, their general characters suggest that they were originally eruptive rocks. Locally the magnesian silicates in these rocks are altered into epidote.

## SERPENTINES.

A large number of observations have been made on these interesting rocks, the result of which are given in the following paper.

## APPENDIX B

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### THE ORIGIN OF THE SERPENTINES IN THE VICINITY OF NEW YORK.

BY FREDERICK J. H. MERRILL.

This paper was written in 1890, as part of a thesis for the degree of Doctor of Philosophy, at Columbia College. It has been withheld from publication a long time, in the hope of making it more complete, but an opportunity for this not having been offered, the paper is published in its original form, leaving to future time the completion of the investigation.

### LIST OF PAPERS ON SERPENTINE CONSULTED IN THE PREPARATION OF THIS ARTICLE.

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## THE ORIGIN OF SERPENTINE.

The origin of serpentine rocks was for a very long time a matter of controversy among geologists. They have been variously regarded as primary deposits, as plutonic rocks, as alteration products of rocks rich in anhydrous magnesian silicates and as the result of metasomatic change in rocks of any kind whatsoever, by the substitution of a hydrous magnesian silicate for some other silicate or carbonate.

About the middle of the present century Bischof and Gustav Rose expressed the unqualified opinion that all serpentines were of secondary origin, but as they were chemists rather than geologists and did not undertake to discuss the various geognostic problems involved in the study of these rocks, they were unable to account for all the phenomena associated with them, and their views, with which those of many other chemists and mineralogists coincided, were not accepted by geologists as conclusive.

Since most of the minerals from which serpentine was held to be derived, viz.: Olivine, enstatite, hornblende, augite, diallage and chondrodite, were believed to belong pre-eminently to eruptive rocks, it was considered inevitable that if the serpentines were all of secondary origin they must have been derived from igneous rocks, and as this hypothesis, in many cases, did not agree with the apparent stratigraphic conditions, it did not gain general acceptance. For example, many serpentines were found distinctly stratified and intimately associated with stratified crystalline rocks, some of which were limestones and obviously not of igneous origin. Dr. T. Sterry Hunt, who has discussed the origin of serpentines at great length,\* while conceding the alteration of olivine and enstatite into serpentine in some cases, considers the association of serpentine with these two minerals to be an evidence of the simultaneous development of hydrous and anhydrous silicates from a magnesian sediment of chemical origin such as he ascribes to all crystalline stratified rocks. He also expresses doubt as to the igneous origin of many of the olivine rocks from which serpentine is held by others to be derived.

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\* Trans. Royal Soc. Canada, Vol. I, § iv, 1883.

In this expression of doubt as to the igneous origin of many magnesian silicate rocks, Dr. Hunt voices the sentiment of most field geologists who have made such rock masses a subject of study. All the common anhydrous silicates of magnesia are found to occur as individual rock masses or as constituents of them in the stratified crystalline terranes. In the opinion that anhydrous and hydrous silicates of magnesia are simultaneously developed from a magnesian sediment or magma, Dr. Hunt seems to stand alone and unfortunately for those who would give due weight to this hypothesis, does not advance any conclusive arguments in its behalf, nor does he record any observed facts in connection with serpentine, which make it apparent that this mineral is ever developed simultaneously with olivine or any other anhydrous magnesian silicate. Dr. Hunt alludes to the studies of Scheerer on the association of olivine and serpentine at Snarum, in Norway, which led that eminent scientist to assert his belief that the two silicates, hydrous and anhydrous, were formed simultaneously, because the alleged pseudomorphs were, in many cases, enclosed in masses of chromite.

According to the writer's understanding of Prof. Scheerer's article,\* the only ground for rejecting the idea of pseudomorphism was that if the crystals of serpentine were produced by the hydration of pre-existing olivine an increase of bulk would ensue which must rend apart by expansion, the matrix of the altered crystal, many of the pseudomorphs being, as already stated, enclosed in masses of chromite which were unfractured and conformed exactly to the surface of the included crystal, which had the characteristic form of olivine though, in its external portion at least, it had the composition of a serpentine.

If this was Scheerer's reason for rejecting the idea of the pseudomorphism of the olivine into serpentine, his objection can not be accepted until it be proven that the chromite masses enclosing the serpentine were formed before the latter. As chromite masses are almost exclusively confined to serpentine rocks and in them, according to Tschermak, are formed by the segregation of the oxides of iron and chromium which are set free in the decomposition of the

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\* Pogg. Ann. Vol. LXVIII, p. 319.

anhydrous silicates of magnesia from the alteration of which he holds all serpentines to be derived, it may be that the chromite matrices of the Snarum pseudomorphs were deposited about them after their formation and were subjected to little or no expansive force, since, after the crystals were thus enclosed and protected from external agencies the process of serpentinization would cease.

Tschermak, in his memoir on the formation of serpentine,\* quotes the words of Gustav Rose and Volger in their description of the Snarum crystals. Rose writes as follows:

"Of two crystals the surface is dark leek-green, soft and a perfect serpentine. On the freshly broken surface, however, the fact is evident that the serpentine is only from one-half to two lines (1-4mm.) thick and graduates into a very light, yellowish-green mass which traverses the crystal irregularly and encloses white areas with a high lustre, which are so hard that they can not be scratched with a knife. These also appear to have cleavage surfaces, but the whole mass is penetrated with fine fissures, and the small individual parts are brilliant on almost every side so that the true cleavage cracks can not be determined.

"Through another crystal passes a cleft about as thick as a sheet of paper, which is filled with very finely fibrous, highly transparent, leek-green chrysotile. From this spread out to right and left, fissures filled in a similar manner, which are nearly perpendicular to the principal crevice and which turn back upon themselves in ramifications which are sometimes very small and sometimes from one to one and one-half lines (2-3mm.) in thickness.

"Where the margins of these turn back quickly they often touch and intersect themselves and the whole mass between them, even when hard and brilliant, is colored green; where they meet each other at greater distances the included mass is white, of greater toughness than in the first crystal and of subconchoidal fracture.

"It is here evident that the whole mass of the crystal was penetrated by fissures which became filled with serpentine and from which the decomposition has proceeded in all directions."

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\* Sitz. Wien. Akad. LVI., 1st Abtheil.

Prof. Volger from his examination of this material arrived at a similar conclusion.

Since the development of microscopic methods of research a large number of eminent investigators have studied the structure and optical properties of serpentine, and all, including Tschermak, Rosenbusch, Kalowsky, Websky, Wiik, Des Cloizeaux, Von Drasche and Fischer, are unanimous in considering it an alteration product of anhydrous magnesian silicates. Prof. Rosenbusch in his late work on rock-making minerals,\* epitomizes the latest knowledge of the subject as follows:—

“Serpentine, according to the mineral from which it is derived, has a fibrous or apparently lamellar structure. The apparent lamellæ may, however, only represent parallel bundles of fibres. The arrangement of the fibres is quite varied. They are sometimes parallel and sometimes confusedly felted and the optical characters of the fibres between crossed nicols change with their dimensions and their arrangement. In parallel aggregates, which are not too finely fibrous, one may recognize with certainty that they are biaxial with very large axial angles the negative bisectrix of which is perpendicular to the axis of the fibre which is the axis of least elasticity. These fibres have a weak refractive power (very near that of Canada balsam) and not inconsiderable double refraction. Chrysotile exhibits these properties very clearly. In the finely and confusedly fibrous aggregates very nearly complete compensation occurs so that these often appear to be isotropic.

“The mineral from which serpentine is most frequently derived is olivine. The alteration begins from the surface and from the crevices and leads to a fibrous structure with simultaneous separation of the iron content in the form of  $\text{Fe}_2\text{O}_3$ ,  $2\text{Fe}_2\text{O}_3$ ,  $+3\text{H}_2\text{O}$  and  $\text{Fe}_3\text{O}_4$ . The new structures of greenish to yellowish-green color are perpendicular to the crystal boundaries and the cracks. Since the alteration takes place from all the cracks (which cross each other confusedly) and from the sides simultaneously, an olivine in which the alteration into serpentine has begun, appears to have a reticulate structure. The serpentine strings form a network of which the meshes inclose olivine

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\* Mik. Phys. der Pet. Wicht. Miner. 2te Aufl. pp. 557-559

still unaltered. As the process goes on, new fissures are cleft in consequence of the increase of volume associated with the alteration and thus render possible the constant increase of the new structures until the olivine is completely transformed."

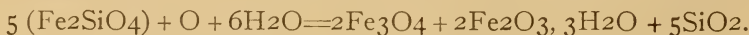
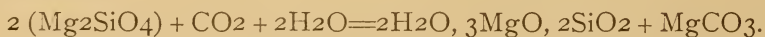
"In the alteration of hornblende and actinolite into serpentine the cleavage planes of amphibole and their oblique separations are very clearly brought out in the arrangement of the serpentine bundles. Between crossed nicols the lines of parallel fibres differentiate themselves in lively colors from the dark ground of the confusedly fibrous field, now running parallel to one another now intersecting one another at an angle of  $124^{\circ}$  to  $125^{\circ}$ , or forming rhombic figures with other angles and rectangles. There results in this way a structure which is characteristic in the highest degree and which Wiegand designated as lattice or window structure."

"Other serpentines, which, microscopically, occasionally show a schistose structure, under the microscope appear to consist of foliated masses which cross each other at right angles and so show a netted structure." "These serpentines appear to have resulted from the alteration of monoclinic pyroxenes."

From the alteration of the rhombic pyroxenes is produced both serpentine and bastite.

According to Tschermak the alteration of olivine into serpentine may be expressed as follows:—

Olivine consists of  $\text{Mg}_2\text{SiO}_4$  and  $\text{Fe}_2\text{SiO}_4$  combined in varying proportions.



A small portion of the  $\text{MgO}$  in the serpentine is replaced by  $\text{FeO}$ .

#### SERPENTINE LOCALITIES NEAR NEW YORK.

The serpentines in the vicinity of New York City are of two general classes:

A. Serpentine masses of large area.

B. Local developments of serpentine in crystalline magnesian limestones.

Of the first class the most extensive is that of Staten Island, N. Y., next in size are those of Rye and New Rochelle in Westchester County, N. Y., and that of Castle Point, Hoboken, N. J. A fifth area is to be found in New York City, on West 60th Street, between 10th and 11th avenues.\*

Of the second class the most prominent examples are at Montville and Mendham in New Jersey and others are found in the continuation of the eastern belt of crystalline limestone through northeastern New Jersey and Orange and Putnam Counties in New York. The most extensive of these, on the east bank of the Hudson River near West Point, was described by Mather under the local name of "cotton rock."† He mentions besides, other localities in Putnam County, notably Huestis' Quarry,  $4\frac{1}{2}$  miles northeast of Cold Spring. In Westchester County serpentine occurs in small masses at the Snowflake Marble Quarry at Pleasantville.

A third class might be constituted of the serpentine which is found in some of the iron mines of Putnam County. The serpentine pseudomorphs of the Tilly Foster Mine have been described at length by Prof. J. D. Dana. (Am. Jour. Sci. III. viii. pp. 454, 455.)

#### THE NEW ROCHELLE SERPENTINE.

The serpentine locality of Davenport's Neck at New Rochelle has long been known to geologists and mineralogists. Its position and stratigraphical relations are shown by the accompanying map. (Pl. VI.)

Prof. J. D. Dana from his observations on this serpentine concludes that it is associated with a limestone bed which is not now visible, having been removed by solution. The writer's study of the locality suggests that the serpentine is derived from magnesian silicate rocks intruded in the Manhattan schist. (Am. Jour. Sci. III. xxxix. p. 391.)

The only exposures now visible are at the northeastern and southwestern extremities near the water's edge, and the outcrops have been so long exposed to the weather that the process of serpentiniza-

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\* This locality is now covered with buildings.

† Cotton rock has been covered by the railroad embankment.

tion is complete and the serpentine itself is disintegrating. The northeastern outcrops are the most extensive and afford the most information concerning the origin of the deposit. The northernmost outcrop is dark green in color, of very coarse texture and has been derived very largely from bronzite, small quantities of which still remain. Succeeding this to the south is a massive rock consisting of hornblende and garnet covering an area of about one hundred and fifty square feet; followed in turn by more of the coarse serpentine, some of which is reddened by the oxidation of its iron content. For one hundred and fifty feet or more, the rock is not visible and then succeeds a fine grained, light green, rather porous serpentine mass which forms a small promontory near the middle of the area. This is overlain with a semblance of stratification which does not harmonise with that of the neighboring gneisses, by a reddish serpentine rock containing actinolite in various stages of alteration. In this portion of the deposit are thick veins of deweylite and chalcedony and a considerable amount of crystalline calcite. In the opinion of the writer the calcite is a by-product of the serpentinization.

Microscopic study of the New Rochelle serpentine suggests that it is chiefly derived from amphibole and bronzite. The occurrence of fibrous amphibole and bronzite or enstatite in connection with the serpentine of this locality has already been recorded by Prof. Dana. In thin sections examined by the writer, crystals of bronzite may be seen in which serpentine has been formed along the transverse crevices. In these bronzite crystals are found also irregular masses of pleonast, the relations of which to the surrounding mass suggest that they are of secondary origin. (Pl. VII.)

Where actinolite has been the source of the serpentine the unaltered mineral verges through a zone of brown, partly decomposed material into the finely fibrous serpentine which contains a very large proportion of minute crystals of magnetite. (Pl. VIII.)

The change from actinolite into serpentine does not seem to be so direct as that from bronzite. The zone of discoloration appears to represent an intermediate stage in which the excess of iron is removed from chemical combination with the silica and set free.

# PLATE VI.



Map of Davenport's Neck, New Rochelle, showing outcrops of serpentine and Ordovician mica schist. Unshaded areas are covered with Quaternary material.  
Geology by F. J. H. Merrill.



PLATE VII.



F. J. H. Merrill, Photo.

ALTERATION OF BRONZITE INTO SERPENTINE, DAVENPORT'S NECK, NEW  
ROCHELLE, N. Y.

Photomicrograph in polarized light, enlargement 22 diameters.



PLATE VIII.



F. J. H. Merrill, Photo.

ALTERATION OF ACTINOLITE INTO SERPENTINE, DAVENPORT'S NECK, NEW  
ROCHELLE, N. Y.

Photomicrograph in polarized light, enlargement 22 diameters.



With regard to the genesis of the minerals from which this serpentine is derived but little can be predicted; there seem to be, however, some reasons for not considering them of sedimentary origin. While the writer does not question the formation of amphibole and bronzite from sedimentary deposits, the evidence of such origin in this case is not conclusive. It is impossible at present to predicate with certainty the geological character of the primitive rock. The outcrops are so limited in extent and so far advanced in alteration that the writer has found no clue to guide him in his investigation of this point. It is safe to say however that the primitive rock mass was different from any now known in an unaltered condition in this terrane. A fragment of bronzite rock was found by Mr. J. I. Northrup in the debris removed from one of the shafts of the new Croton Aqueduct near Tarrytown and this may have been a part of such rock mass as that which gave being to the New Rochelle serpentine, but unfortunately nothing can be ascertained concerning its source.

The origin of the deposits from which this serpentine and its congeners have been derived remains the most important question connected with their history, and unfortunately we can only reason upon analogy in discussing it. In all probability the magnesian silicate rocks which by their alteration have yielded these serpentines were similar in their origin to the amphibolites and pyroxenites which abound in Westchester county. In modern sedimentation no evidence has been recorded of an alteration of conditions which would yield in small quantity a deposit having the composition of a magnesian silicate when immediately before and after it the sediment was chiefly composed of silica and aluminous silicates. In *composition* the amphibolite and pyroxenite beds of the Manhattan Group bear the same relation to the strata which enclose them as the intrusive mass of the Palisades bears to the beds of sandstone and arkose between which it is now included. There is nothing but their somewhat foliated condition to suggest that they are of sedimentary origin and this characteristic has been shown to result frequently from dynamo-metamorphism.

The former hypothesis that serpentine is largely derived from the alteration of magnesian limestone or dolomite does not seem to be

supported by recent investigations. In the literature to which the writer has access, the only recorded instance of such derivation is that of a pseudomorph collected from the Tilly Foster Mine, the form and structure of which suggested to Prof. J. D. Dana that it had been derived from a crystal of dolomite.\* Mr. George P. Merrill has happily suggested, in the case of the Montville serpentine, that the excess of silica set free in the decomposition of the diopside has to some extent combined with the magnesia of the enclosing dolomite and thus formed a serpentine in addition to that formed by the alteration of the pyroxene. It is evident that a dolomitic limestone can only yield serpentine through the action of silicated waters, while the magnesia-iron minerals above mentioned will yield serpentine under the influence of ordinary atmospheric waters.

In the present opinion of the writer the origin of the New Rochelle serpentine has been as follows:

The mica schists were formed by sedimentation and metamorphism. The amphibolites and other magnesian silicate rocks were intruded and by subsequent compression attained their foliated structure. Orographic disturbance subsequently brought the strata into their present attitude and finally erosion removed the covering of mica schist and laid bare the truncated folds. Atmospheric waters then had free access to the magnesian silicates and the process of de-ferrugination and hydration began and resulted in the formation of the serpentine. The excess of silica was carried off and deposited in the form of chalcedony of which large masses and minute veins occur in the deposit, and the excess of iron appears as magnetite and chromite, while according to the combinations into which the magnesia entered, various varieties of serpentine were formed, together with magnesite, talc and deweylite.

The writer is not disposed to attribute any very great geological antiquity to the serpentine. Under favorable conditions it forms quite rapidly. At Stony Point on the Hudson River, the writer has observed a surface of peridotite, which had apparently been swept clean by the ice sheet, covered by a layer of serpentine about one-

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\* Since the above was written some material has been given to the writer by Dr. Hunt of the Brooklyn Institute, which in appearance corroborates Prof. Dana's conclusion.

fourth of an inch thick. As in this case only a small portion of the rock had by its decomposition yielded serpentine, and the layer observed by the writer had been leached out of the rock, it is reasonable to infer that a considerable depth of the rock might, since the glacial epoch, have been changed into serpentine had all of its minerals yielded that alteration product.

From what is known of the erosion of the region about New York it may be inferred that the rock mass which yielded the New Rochelle serpentine was exposed to the action of atmospheric agencies not earlier than the Mesozoic age.

### THE STATEN ISLAND SERPENTINE.

The general characteristics and extent of this deposit have been described by Dr. N. L. Britton, but the question of its origin is not entirely settled. Throughout most of its extent this area has suffered so complete an alteration as to yield no traces of the mineral from which it was derived. Mr. Gratacap records the presence of traces of unaltered hornblende in specimens from Bard avenue and elsewhere. In a well boring made through the serpentine some fibrous amphibole or actinolite was found in a comparatively unaltered condition. (Trans. N. Y. Acad. Sci., Vol. I, p. 58.) Dr. A. A. Julien (loc. cit.) states that he has found traces of unaltered hornblende in Staten Island serpentine.

In none of the material which the writer has examined has he found unaltered particles of the primary mineral, but there is frequently present *a reticulate structure similar to that which Rosenbusch has described and illustrated as characteristic of serpentine derived from olivine*. In a large number of sections examined by the writer the "lattice structure" characteristic of serpentine derived from hornblende was wanting, the angles between the cracks being more nearly those of pyroxene than of hornblende. It is not improbable that more than one magnesian silicate has contributed to its origin.

In the process of alteration limonite and free silica were the chief by-products. The former appears in the once extensive bed of limonite which has been used as an iron ore, and the latter in the groups of quartz crystals which so frequently occur in the former.

If there were any considerable amount of alumina in the primitive minerals it was probably carried off and deposited with the limonite. The manner in which this ore originated accounts for its freedom from sulphur and phosphorus.

#### THE SERPENTINE OF RYE AND HOBOKEN.

After studying a large amount of material from these two localities the writer is unable to contribute any new facts regarding their origin. The outcrops are so far decomposed as to afford no traces of the primitive mineral. Dr. A. A. Julien (*loc. cit.*) mentions his discovery of traces of hornblende in serpentine from Hoboken.

#### SERPENTINES ASSOCIATED WITH LIMESTONES.

The distribution of these serpentines has already been described. The deposits at Montville, N. J., are of much interest. Here the serpentine is derived from segregated masses of diopside enclosed in the magnesian limestone.

Mr. G. P. Merrill's monograph on the subject\* shows very clearly the chemical relations of the primitive mineral and its alteration product, and discusses one of the few cases of the formation of serpentines from the magnesia of a dolomitic limestone. At Mendham the serpentine is of similar origin to that of Montville and pyroxenes easy of decomposition occur throughout this belt of limestone of which the extent has already been mentioned.

In Westchester County, N. Y., at Pleasantville and elsewhere the serpentine is likewise derived from magnesian silicates, chiefly of the pyroxene group but occasionally having the characteristics of an olivine.

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\*Proceed. U. S. Nat. Mus., Vol. XI.







